Modeling Cell Temperature and Performance of Photovoltaic Systems

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Motivation for Adaptable Cell Temperature Model

- Cell temperature affects panel efficiency:
  PV performance models typically require cell temperature inputs.
- The mounting of a panel can vary and affects the cell temperature.
  - Open rack
  - BIPV
  - Roof Integrated

Steady State Energy Balance

Absorbed radiation: HDKR model

Sky Temperature: Berdahl and Martin (1984)

Ground temperature

Open rack: $AVE(T_{amb}, T_{cell})$

BIPV: T_{amb}

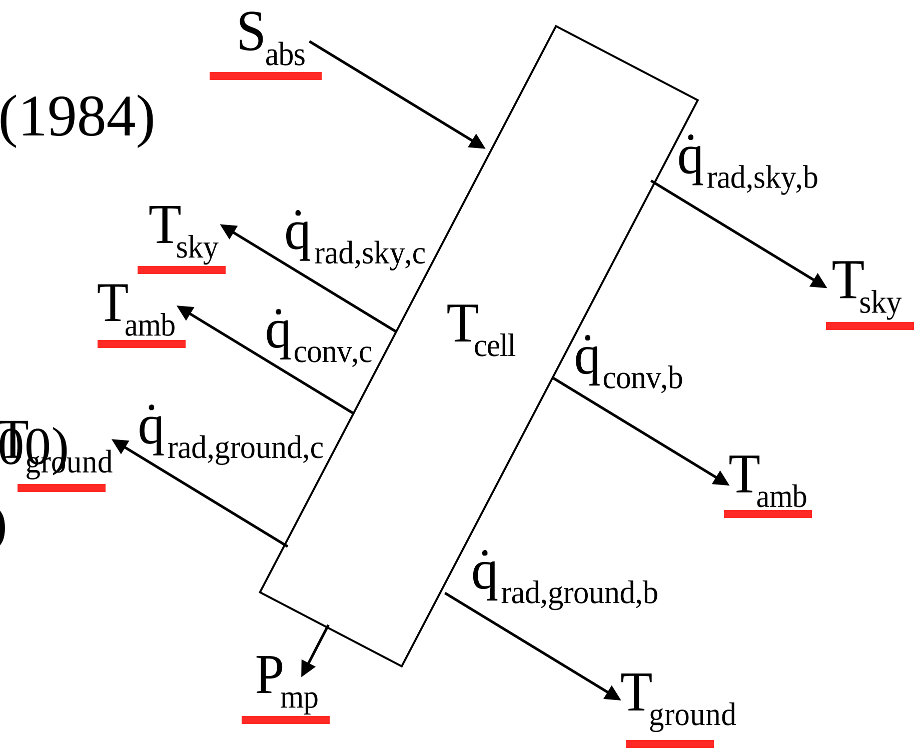
Turbulent forced convection: Schlichting (2000)

Free convection: Raithby and Holland (1998)

Combining forced and free convection: $\bar{h}_{total} = \sqrt[3]{\bar{h}_{forced}^{3} + \bar{h}_{free}^{3}}$

Power: 5-parameter model

Duffie and Beckman (2006)



$$S_{abs} = \dot{q}_{conv,c} + \dot{q}_{conv,b} + \dot{q}_{rad,sky,c} + \dot{q}_{rad,sky,b} + \dot{q}_{rad,ground,c} + \dot{q}_{rad,ground,b} + P_{mp}$$

Validation Data

- Building Integrated
  - NIST, Maryland
  - South wall vertical mounting, backside insulated
  - Mono-Si, 6 mm glass cover
  - Poly-Si, ETFE cover
  - Wind speed measured near panel

- Open Rack
  - Sandia (NM) mono-Si panel
  - NREL (CO) HIT panel
  - Fixed tilt = latitude

Additional Cell Temperature Models Evaluated

- Duffie and Beckman (2006)

$$\frac{T_{cell} - T_{amb}}{T_{NOCT} - T_{amb,NOCT}} = \left(\frac{9.5}{5.7 + 3.8 \times u}\right) \times \left(\frac{S - P_{mp}}{S_{NOCT}}\right)$$

- Skoplaki (2008)

$$T_{cell} = T_{amb} + \omega_m \left(\frac{0.32}{8.91 + 2u_\infty}\right) G_T$$

where ω_m is dependent on the mounting of the panel

- King (2004)

$$T_1 = G_T \times exp \;\; a + b \times u_\infty \;\; + T_{amb}$$

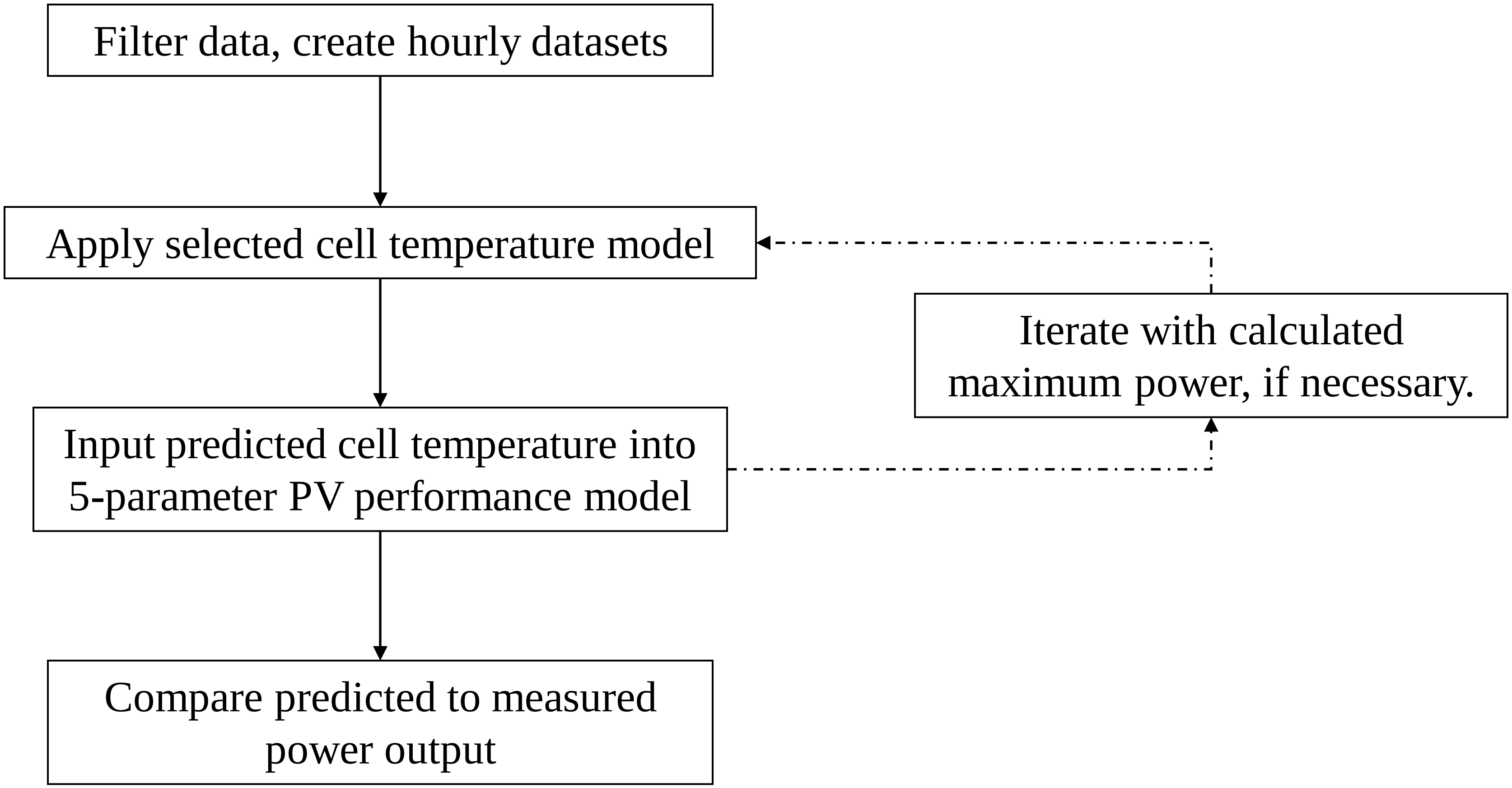
$$T_{cell} = T_1 + \left(\frac{G_T}{G_{T,ref}}\right) \Delta T$$

where a, b, and ΔT are empirically (mounting and panel specific) determined coefficients.

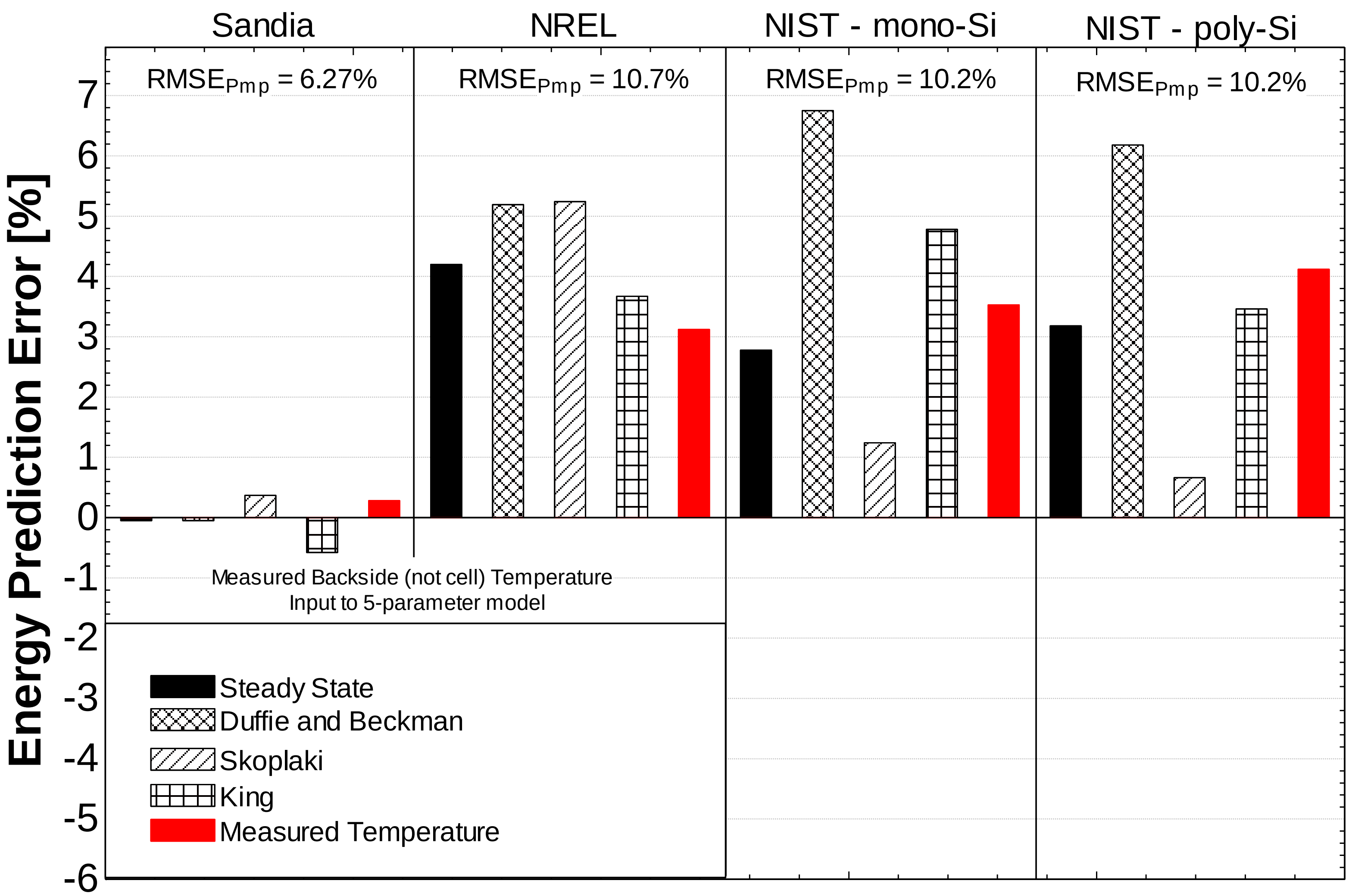
Cell Temperatuure Model Comparison: Skoplaki vs. Duffie and Beckman

Assumptions and Inputs	
Duffie & Beckman	**Skoplaki**
Installed NOCT	Open-rack NOCT = 47 C Mounting coefficient, ω = 2.4
Calculated Absorbed Radiation	τα=0.9
Calculate power output from 5-parameter model	Constant cell efficiency = 0.12
$h = 8.91 + 2u_{\infty}$	$h = 5.7 + 3.8u_{\infty}$

Simulation Procedure



Annual Simulation Results



Summary of Simulation Results

- 5-parameter model with measured cell temperature results in <4.5% annual energy prediction error.
- All cell temperature model results for open rack panels are consistent and accurate when compared against 5-parameter model with measured temperature (backside) input.
- Greatest divergence of cell temperature model results observed for BIPV panels.
  - Skoplaki & Duffie and Beckman results become less accurate. Why?

Explanation of Cell Temperature Model Divergence

- Hypothesis: For integrated mountings, measured NOCT becomes a less accurate estimate of cell temperature at testing conditions.

	Open Rack - Sandia	Open Rack - NREL	BIPV (mono-Si)	BIPV (poly-Si)
Assumed NOCT (Skoplaki) [C]	47	47	85	85
Reported NOCT [C]	46	44	67	62
Predicted NOCT [C]	42	43	78	74
Standard Deviation [C]	**2.6**	**1.9**	**9.0**	**11.2**

  - Mounting conditions become more difficult to replicate/predict
  - Correction factor chart becomes less accurate

NOCT Correction Factor Plots

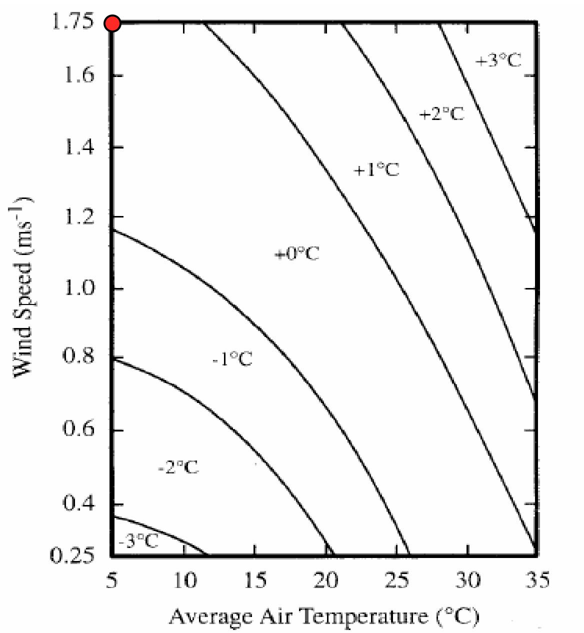
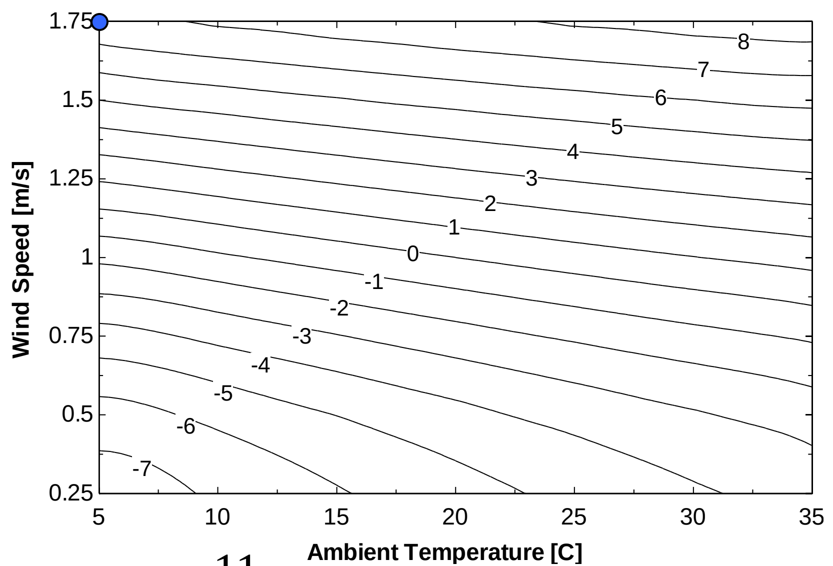


FIG. A1.1 NOCT Correction Factor

IEC NOCT Correction Factor

Correct Factor @ 1.75 m/s, 5 C:

- IEC: 0-1°C
- Predicted: 6-7°C



Predicted c.f. chart for BIPV mono-Si

Recommendations

- NOCT values for integrated mountings are difficult to measure and may be inaccurate due to
  - Correction factor charts
  - Inability to measure NOCT under intended mounting conditions
- Improve model prediction by
  - Report actual conditions during NOCT test
  - Develop and use correction factor chart specific to panel mounting